

*What can the highest angular resolution bring to stellar astrophysics?*

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## OLIVIER CHESNEAU'S WORK ON NOVAE

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**Abstract.** Olivier Chesneau founded a brand new field of observational astrophysics with his attempts to resolve the novae expanding fireball from the very first days of the explosion. With the images he could get, he showed that novae do indeed explode in an aspherical way, leading to a change of paradigm for the physics of these yet-poorly understood catastrophic systems. He also set the stage for a new way of estimating novae distances, by directly measuring the sky-size of the fireball and comparing it with spectroscopic scales, taking into account the tremendous effects of the fireball geometry.

### 1 Introduction

Novae are thought to be the progenitors of type-Ia supernova, the standard candle for remote distance gauge in the Universe.

They are symbiotic stars, made of a giant star and a white dwarf orbiting around each-other. These two close-by stars interact through a Roche lobe overflow on the giant star side, feeding an accretion disk on the white dwarf side. The accretion piles up hydrogen in large quantity on the surface of the white dwarf, until the accreted mass is sufficient to ignite again nuclear reactions. A thermonuclear explosion occurs, blowing away most (but not all) of the material accreted onto the white dwarf. The very faint stellar pair light is quickly overcome by an extremely bright fireball, which soon engulfs the whole system, and later relax in the interstellar medium in timescales of months to years. Novae exhibit changes of up to 15 magnitudes within a few days. Once the relaxation is over, the process of accretion / explosion cycles can start again, but the remaining mass of hydrogen at each explosion piles up on the surface of the white dwarf, accelerating the cycle every time up until a type-Ia supernova occurs.

Novae remnants often show aspherical shapes, which were not well-explained before, as the fireball was supposedly round in the first moments of the explosion.

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Olivier Chesneau realized that he could get the shape of the fireball in the very first days of the explosion with the new high-angular resolution techniques he was using in other fields (see a summary of his research in the previous articles Lagadec 2015; Millour 2015). This would enable him to trace the link between the spherical fireball and aspherical remnant. Getting to such early moments mean having a sufficient angular resolution of a few milli-arc-seconds, unreachable by conventional telescopes, even equipped with adaptive optics. Only the long-baselines of stellar interferometers can attain such a high angular resolution.

O. Chesneau found out that no multi-baselines studies of nova had been done with interferometry, and that such observations could be a revolution for the study of the environments of such objects. Time series of interferometric observations enable one to gauge the angular expansion of the fireball. Knowing its expansion velocity (with simultaneous spectroscopy) can lead to a direct estimate of the distance of the symbiotic system.

Of course, if the nova fireball is aspherical, or even more: asymmetric, then a catastrophic bias in the distance estimate may sneak in the whole process. Fortunately, such observations can also enable the study of the geometry of the nova from the very early stages of the explosion, and the monitoring of its evolution. His dream was to be able to get both the geometry from the first blink of the explosion, and to monitor the expansion of the fireball, making accurate distance estimates of galactic novae slide from the science-fiction to science side.

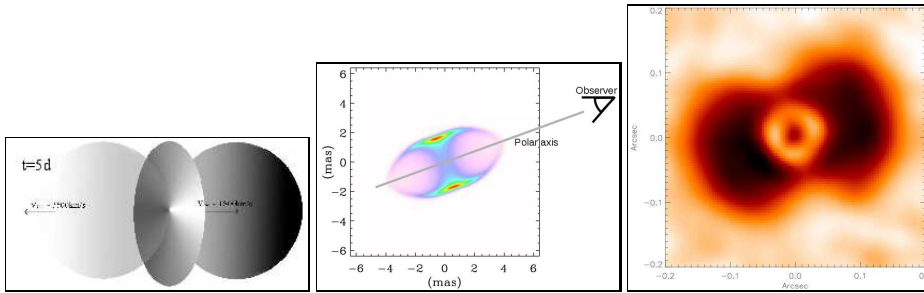
In addition, for dust-producing novae, the quantity of dust production over time after the nova explosion can be accurately weighted.

## 2 Live formation of bipolar novae: RS Oph & T Pyx

O. Chesneau started discussing with different novae specialists to prepare an ESO proposal to observe novae with the VLTI. He estimated that he should be able to observe a nova with AMBER every 2 years and with MIDI every 4 years, as the targets needs to be closer than  $\sim 4$  kpc to be large enough and bright enough for the VLTI. He wrote a proposal with a few colleagues from Grasse, but it was rejected. He nevertheless decided, together with Christian Pollas and Alain Spang to monitor potential targets. The eruption of the recurrent nova RS Oph in 2006 was a perfect opportunity for O. Chesneau to propose ESO DDT (Director Discretionary Time) observations of a nova.

He was incredibly fast in writing down the proposal. The nova exploded the 12<sup>th</sup> of February 2006, the DDT was basically ready the 13<sup>th</sup> (late in the night...). The DDT was also accepted extremely fast due to the accidental presence of the whole DDT board at a meeting in ESO at that time. The observations were therefore carried out just 5.5 days after the outburst, the 18<sup>th</sup>, and a first set of high-quality AMBER data was delivered. Unfortunately, the following sets were of much lower quality, making them unusable in practice.

The enthusiasm of O. Chesneau was only impaired by the difficulty to interpret this extremely sparse data with a somewhat physical model. As pragmatic as he could be, he decided to perform a simple analysis with simple geometric models



**Fig. 1.** Bipolar fireballs everywhere! **Left:** the vision of O. Chesneau on RS Oph in (Chesneau & Banerjee 2012). **Middle:** T Pyx bipolar fireball, as seen by AMBER and PIONIER as a face-on bipolar nebula (Chesneau et al. 2011). **Right:** NACO/VLT 2010 K band image of V1280 Sco, revealing a bipolar dusty nebula (Chesneau et al. 2012).

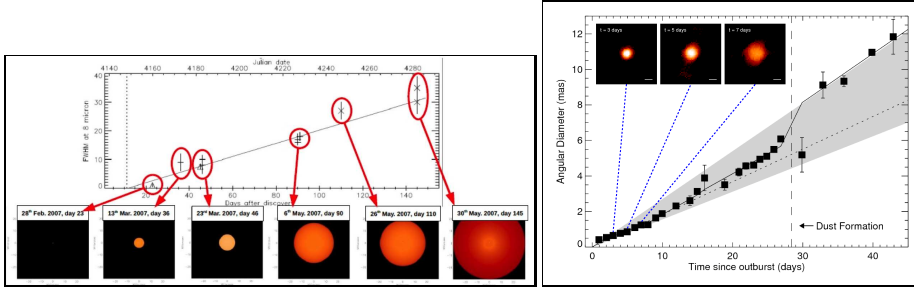
developed by N. Nardetto. He could show this way that the fireball was not spherical (see Fig. 1, left), already in the early stages of the explosion, and that it was indeed a fireball (Chesneau et al. 2007). The lack of time series in the AMBER data was a big frustration for him as he could only fulfill one of his two main objectives, i.e. get the shape of the fireball but not the distance.

He later could interpret AMBER/VLTI and PIONIER/VLTI data of another nova: T Pyx. Indeed, the broadband PIONIER/VLTI data were consistent with a round fireball, but the spectroscopically resolved AMBER data enabled O. Chesneau to resolve the third dimension, providing evidence that the nova was indeed bipolar in the very early stages of the explosion, but seen almost exactly pole-on (see Fig. 1, middle). A complete interpretation was published using a sophisticated phenomenological model that was developed by A. Meilland.

This new point of view on the system could provide an explanation to the stunning observed slow motion HST knots around the symbiotic system, if they were situated in an on-sky equatorial over density (Chesneau et al. 2011). But again for T Pyx, the difficulty of scheduling telescope time in a continuous manner was a burden to perform the full study of the system as a function of time, and no clear coherent time-dependent view could be used to constrain the distance to the system.

### 3 Witnessing the start-up and evolution of a dust factory: V1280 Sco

The study of dust around novae was made possible by the explosion in 2007 of the dust producing nova V1280 Sco. As soon as it exploded, it appeared to be a slow nova, as it took 10 days to reach its brightness maximum. O. Chesneau decided to monitor this object right-away, with AMBER/VLTI and MIDI/VLTI observations. This time, the DDT committee was not together and the process took the regular time to go for proposal acceptance, but O. Chesneau did not know that the process was 1 to 2 weeks long, and therefore was extremely anxious



**Fig. 2. Left:** Evolution of the size of the circumstellar dust shell around V1280 Sco as seen by MIDI/VLTI, assuming the shell to be spherical (Chesneau et al. 2008). **Right:** The fireball expansion of Nova Delphinus 2013 witnessed by the CHARA array (Schaefer et al. 2014).

of not getting any data on this very interesting nova. The proposal was finally accepted and he obtained data as soon as day 23 after the explosion, till day 145. As the nova produced dust, its optical and near-infrared brightness decreased quickly, making AMBER observations soon unfeasible. It was thus important to monitor it photometrically in the infrared to make the most out of the MIDI/VLTI observation. This happened to be possible via a very active collaboration with Dipankar Banerjee and his colleagues from Mt Abu in India. The VLTI follow-up was hectic as O. Chesneau had to permanently adapt his observing strategy with this ever-changing object, and the observatory had difficulties to catch up in their observing planning.

The MIDI observations immediately revealed that the dust shell was expanding (Fig. 2, left) and, using radiative transfer modelling, O. Chesneau showed that it was producing large amounts of dust (Chesneau et al. 2008). This work was made assuming that the expanding shell was spherical, due to the sparse UV coverage of the observations. Again, O. Chesneau was frustrated by these observations because he could only get a rough distance estimate, knowing that the geometry of the fireball was wrong (as some MIDI data were showing odd behavior compared to a round fireball), but anyway these results had some echo following a press release from ESO.

To further study the morphology of the ejecta of V1280 Sco, O. Chesneau decided to use direct imaging techniques. Indeed, as the nova shell was expanding, its angular dimension became appropriate to be directly resolved by the VLT. He made use of the adaptive optics imager NACO/VLT (with a resolution of  $\sim 50$  mas in the K band) and the mid-infrared imager VISIR/VLT (with a spatial resolution of  $\sim 300$  mas at  $10\mu\text{m}$ ). He secured observations in 2009, 2010 and 2011, from  $t=877$  days after discovery until  $t=1664$  days. These observations were strikingly spectacular, and O. Chesneau's enthusiasm was communicative every time he was receiving new data. An expanding hourglass dusty shell could be monitored almost in real time (see Fig. 1, right)! The nebula more than doubled in size between July

2009 and July 2011 and we inferred a mean expansion rate of  $\sim 0.39$  millarcsec per day in the direction of the major axis. Most of the dust mass appears to be in the polar caps, implying that the mass loss was predominantly polar (Chesneau et al. 2012).

#### 4 Getting direct and accurate distances to Novae explosions

All the previous attempts were missing one of the time-variable or geometry information, or, when both were available for T Pyx, they had a too low quality to be of much use.

The last nova O. Chesneau could observe was Nova Delphini with several CHARA instruments. Although he was already quite sick, he was involved heavily in the observations preparation and follow-up. This particular interferometric campaign was the first one making possible to get both the geometry and time-variations information in a self-sustained data set (see Fig. 2, right), leading to a nice paper (Schaefer et al. 2014) where both the geometry and an accurate distance estimate could be obtained.

#### 5 Conclusion

The work on novae continues after the demise of O. Chesneau, as the monitoring framework and collaboration network he set up still exist. His contributions to the field have changed quite drastically the view of novae fireballs, and theoretical works are ongoing to try to understand why the bipolar nova fireballs seem to be ubiquitous (See e.g. Mohamed et al. 2013).

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